Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches

Philip Dellinger, Chief
Ground Water/UIC Section
EPA Region 6

State Working Group Members

- Lawrence Bengal Arkansas Oil and Gas Commission
- Douglas Johnson Railroad Commission of Texas, retired
- Charles Lord Oklahoma Corporation Commission
- Tom Tomastik Ohio Department of Natural Resources, retired
- James A Peterson West Virginia Department of Environmental Protection
- Chuck Lowe Ohio EPA
- Jim Milne Colorado Oil and Gas Conservation Commission
- Denise Onyskiw Colorado Oil and Gas Conservation Commission, retired
- Vince Matthews Colorado Geologic Survey, retired

Expert Review Panel

- Brian Stump, Southern Methodist University
- Chris Hayward, Southern Methodist University
- Scott Ausbrooks, Arkansas Geological Survey
- Steve Horton, Center for Earthquake Research and Information, U of Memphis
- Ernest Majer, Lawrence Berkeley National Laboratory
- Norman Warpinski, Pinnacle
- John Satterfield, formerly with Chesapeake Energy
- Cliff Frohlich, Bureau of Economic Geology, University of Texas
- David Dillon, National Academy of Science
- Shah Kabir, Hess Energy
- Bill Smith, National Academy of Science, retired

Presentation Summary

- Overview of Study Approach
- Discussion of engineering tools
- Summary of findings and recommendations

Overview of Study Approach

- Timeframe for effort

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

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Overview of Study Approach

- Literature review and compilation
  - Peer reviewed material only
  - Comprehensive, but moving target

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
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Overview of Study Approach

- Analysis of four case examples
  - Arkansas
  - North Texas
  - West Virginia
  - Youngstown Ohio

Overview of Study Approach

- Analysis of four case examples
  - Geologic site summary
  - History of seismicity
  - State actions
  - Application of reservoir engineering methods
  - Lessons learned

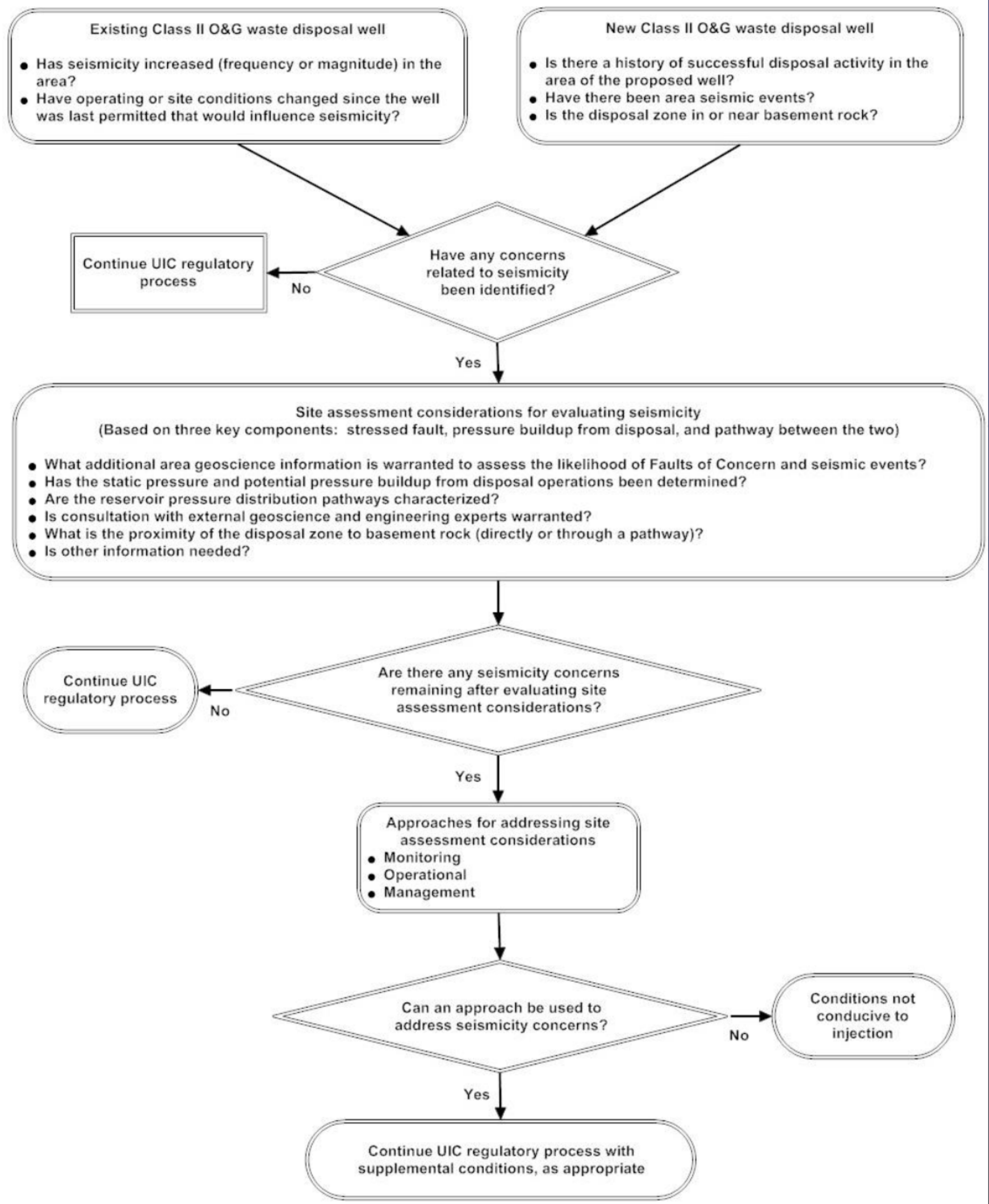
Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Development of decision model
  - Received much input throughout process
  - Comprehensive thought process - not specific
  - Founded on Director Discretionary Authority

Injection-Induced Seismicity Decision Model for UIC Directors*
(Based on the decision model discussion in Appendix B)



* Decision model is founded on Director discretionary authority

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Fundamentals of induced seismicity
  - Broaden potential audience
  - Provide a general reference
  - Includes geoscience and engineering aspects
  - Appendices of report

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Explore petroleum engineering methods
  - Data obtained from suspected wells in case examples were analyzed.
  - Two fundamental approaches were used.
    - Pressure transient testing (falloff)
    - Operational data analysis.

Presentation Summary

- Overview of Study Approach
- Discussion of engineering tools
- Summary findings and recommendations

Discussion of Engineering Tools

- A few points.
  - Quality of data is crucial.
  - These methods are an interpretive tool, not a fix-all.
  - PE tools can determine if fracture flow is predominant.
  - Fractured reservoirs can transmit pressure buildup over great distances.
  - PE tools can detect reservoir changes at distance, including faults.
  - Correspondence between well behavior and seismicity was apparent in some case example wells.

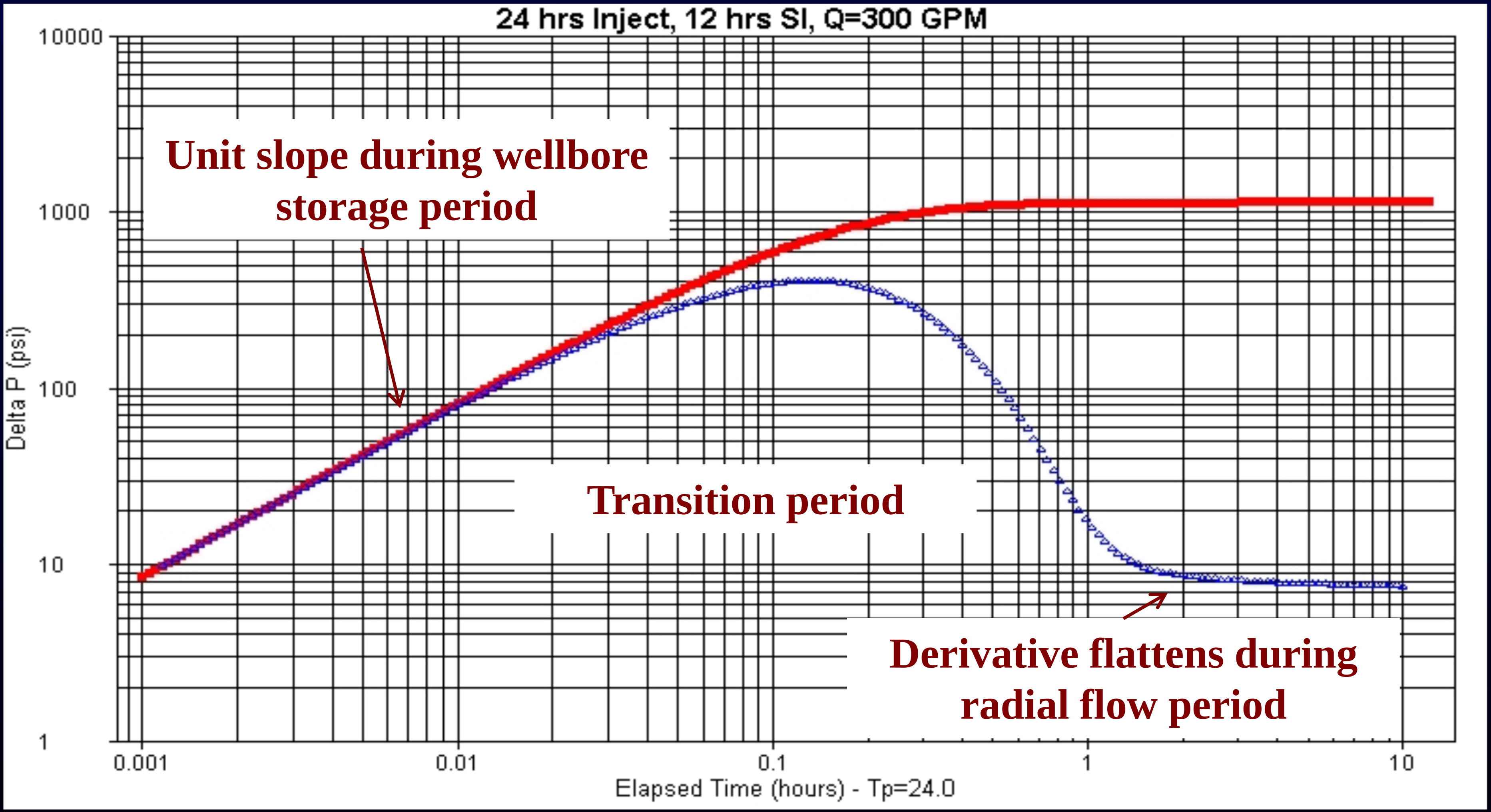
Discussion of Engineering Tools

- Two fundamental approaches
  - Well testing
    - Pressure transient or falloff testing can determine if a reservoir is fractured, as well as static formation pressure.
  - Analysis of operational data
    - Hall plots using operational data (rates and pressures) indicate changes in transmissivity (ease of injection) at distance.

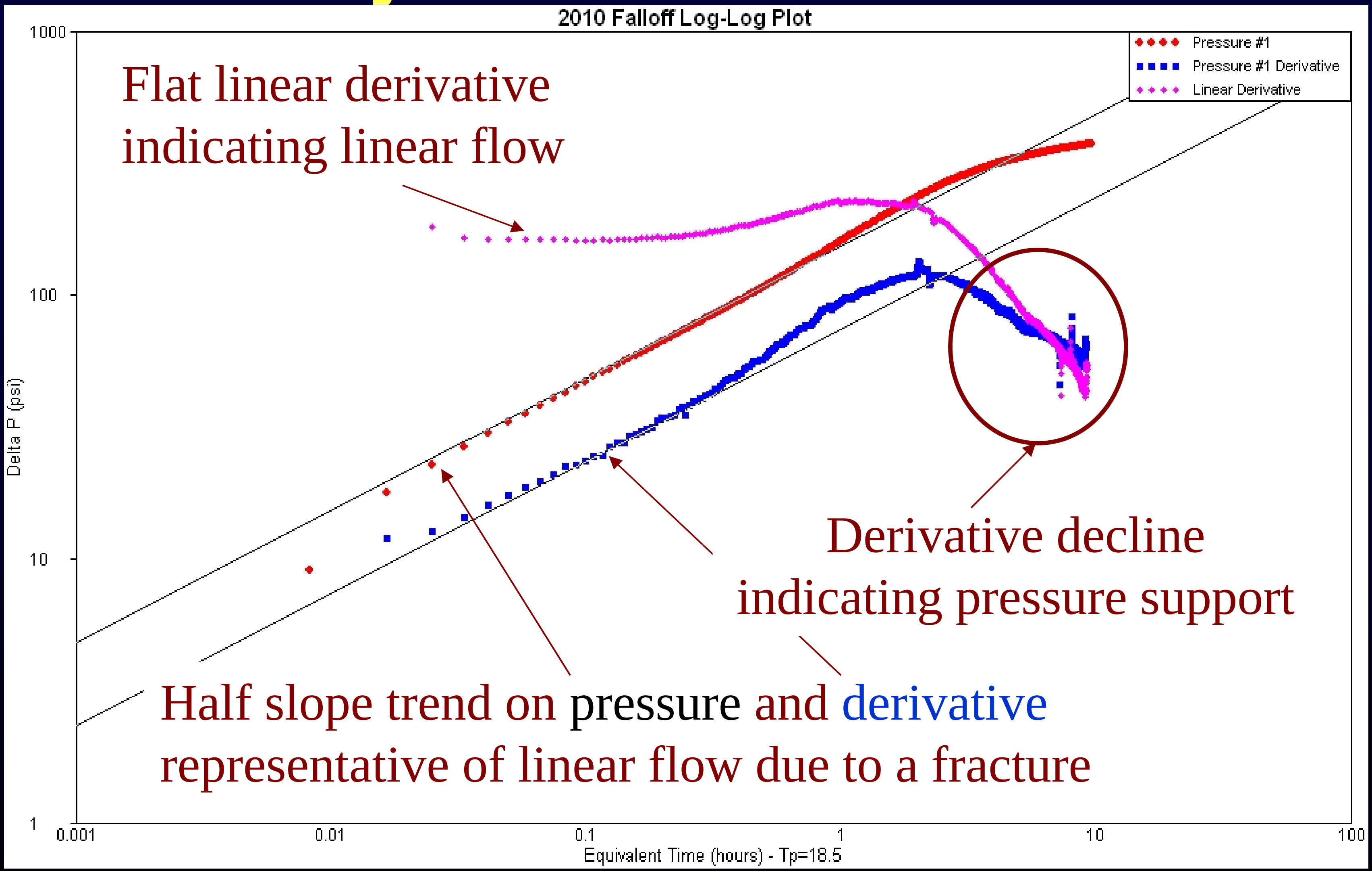
Discussion of Engineering Tools

- Examples – falloff testing

Log-Log Plot of a Disposal Well Exhibiting Radial Flow



Falloff Test Indicating Fractured Injection Formation



Discussion of Engineering Tools

- Examples – Hall plots

Presentation Summary

- Overview of Study Approach
- Aspects of engineering tools
- Summary of findings and recommendations

Summary of Findings and Recommendations

- Proactive approach is preferred
  - Engage operators
    - Additional site geologic data
    - Voluntary actions
    - Increased operational data
  - Monitor seismicity trends in regional area
  - Characterize injection reservoir (testing)
    - Case examples – deep fractured reservoirs
    - Fractures more likely to communicate pressure buildup long distances
    - Buildup can be directional
    - Fractured reservoirs can result in communication with basement rocks, lower confining strata is important

Summary of Findings and Recommendations

- Assure high quality operational data
- Permitting contingencies (green, yellow, red lights) are an excellent tool to address site uncertainties
- Increased seismometers better define seismic activity.

  - Engage operators
    - Additional site geologic data
    - Voluntary actions
    - Increased operational data
  - Monitor seismicity trends in regional area
  - Characterize injection reservoir (testing)

Final Words

- EPA Region 6 is preparing a seismicity training module for injection well regulators.

Overview of Study Approach

- Literature review and compilation
  - Peer reviewed material only
  - Comprehensive, but moving target
- Analysis of four case examples
  - Geologic site summary
  - History of seismicity
  - State actions
  - Application of reservoir engineering methods
  - Lessons learned
- Development of decision model
  - Thought process - not specific
  - Example of ODEQ support –
    - site assessment may never be sufficient
- Explore petroleum engineering methods
  - Quality of data is crucial
  - The importance of Fractured reservoirs can transmit pressure b
  - PE tools can determine if fracture flow is predominant
  - PE tools can “see” reservoir changes at distance including faults
  - Correspondence between well behavior

Lessons Learned From Case Examples

- Engage operators of suspected wells early
- Analyze existing operational data
  - Provides insight into the behavior of the disposal zone (fracture flow or radial flow)
  - Hall plots can show reservoir changes/features away from well (increased ease or difficulty of fluid flow).

Seismicity in Areas of Oil and Gas Activities

Philip Dellinger
Chief, Ground Water/Underground Injection Control Section
EPA Region 6

Disclaimer

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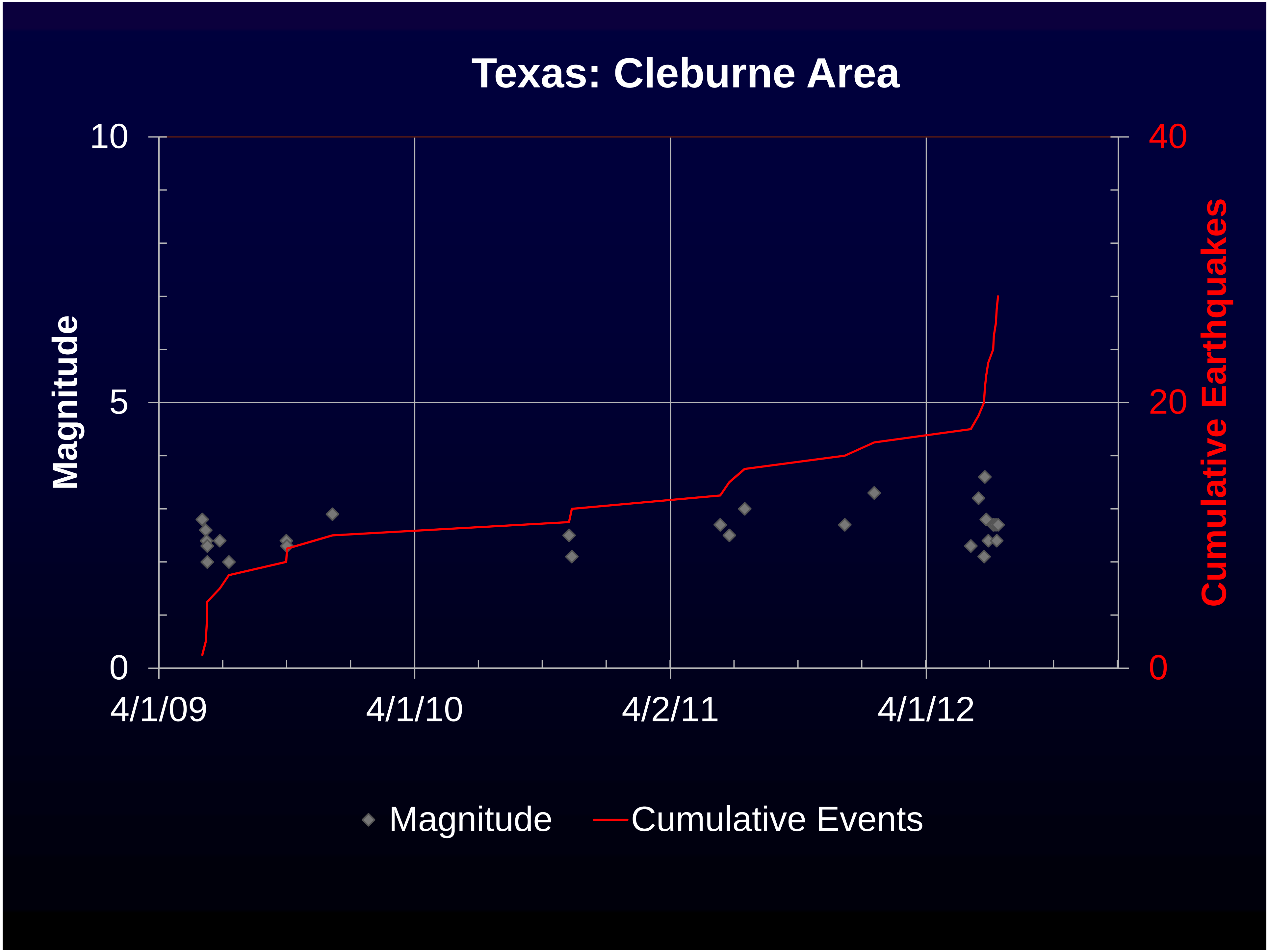
Presentation Summary

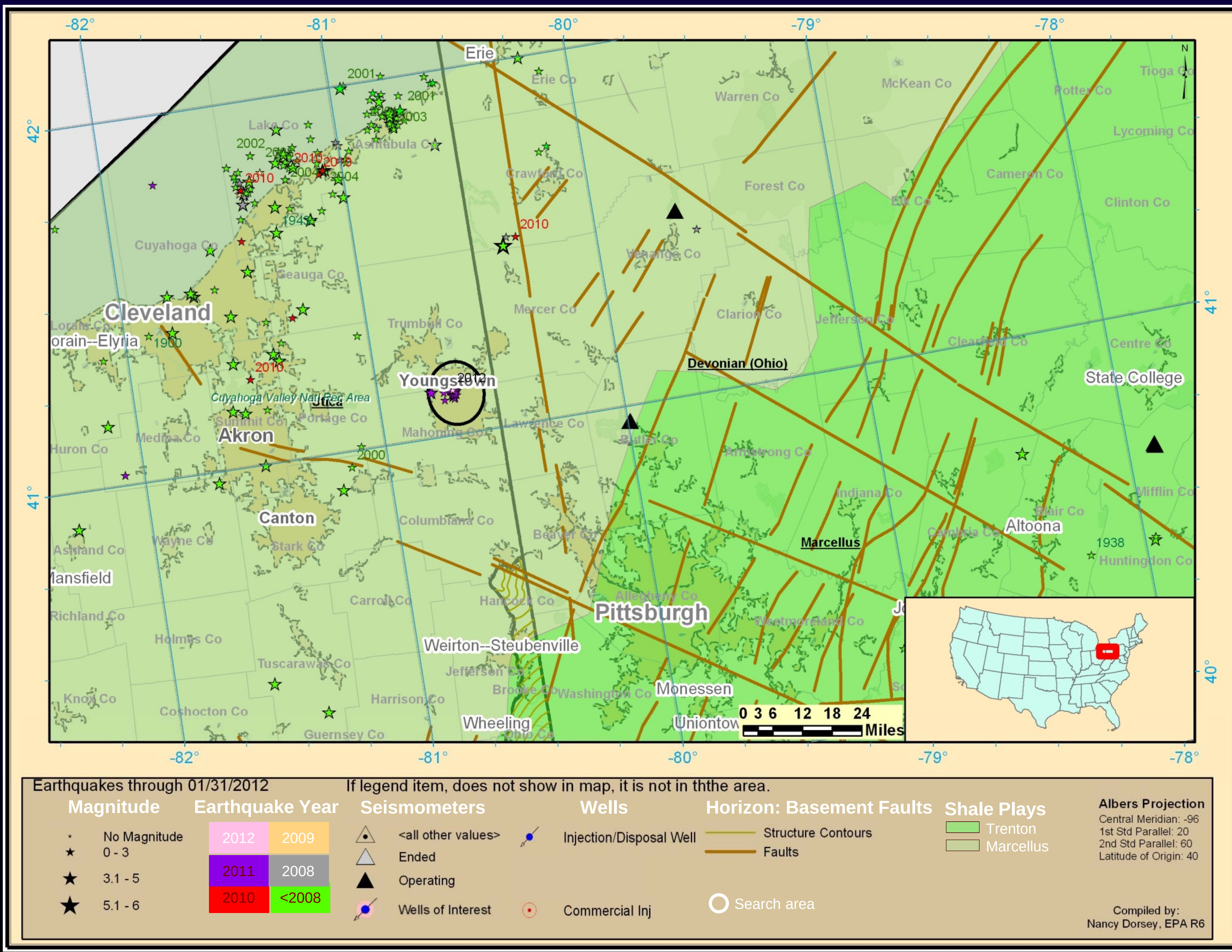
- Background on underground injection
- Relevant seismicity fundamentals
- Selected recent cases of seismic activity
  - Arkansas
  - North Texas
  - Youngstown, Ohio
- Tools for minimizing seismicity



Texas: Cleburne Area
10
5
0
40
20
0
Magnitude
Cumulative Earthquakes
4/1/09
4/1/10
4/2/11
4/1/12
Magnitude
Cumulative Events

Youngstown, Ohio

- March 2011 – First of a series of low magnitude events.
- Events continued through 2011, culminating in a M4.3 event on December 31.
- A nearby disposal well was shut in immediately



Erie
Erie Co
Warren Co
McKean Co
Potter Co
Tioga Co
Lake Co
Ashtabula Co
Crawford Co
Forest Co
Cameron Co
Lycoming Co
Elk Co
Clinton Co
Cuyahoga Co
Geauga Co
Venango Co
Cleveland
Lorain--Elyria
Mercer Co
Trumbull Co
Clarion Co
Jefferson Co
Clearfield Co
Centre Co
Devonian (Ohio)
Youngstown
State College
Cuyahoga Valley Nat Rec Area
Portage Co
Summit Co
Medina Co
Akron
Mahoning Co
Lawrence Co
Butler Co
Armstrong Co
Huron Co
Indiana Co
Mifflin Co
Canton
Columbiana Co
Blair Co
Altoona
Cambria Co
Beaver Co
Wayne Co
Stark Co
Ashland Co
Marcellus
Huntingdon Co
Mansfield
Carroll Co
Hancock Co
Allegheny Co
Richland Co
Pittsburgh
Westmoreland Co
Holmes Co
Weirton--Steubenville
Tuscarawas Co
Jefferson Co
Brooke Co
Washington Co
Monessen
Knox Co
Harrison Co
Coshocton Co
Wheeling
Uniontow
Guernsey Co
Ohio Co
0 3 6 12 18 24
Miles
Earthquakes through 01/31/2012
If legend item, does not show in map, it is not in ththe area.
Magnitude
No Magnitude
0 - 3
3.1 - 5
5.1 - 6
Earthquake Year
2012
2009
2011
2008
2010
<2008
Seismometers
<all other values>
Ended
Operating
Wells of Interest
Wells
Injection/Disposal Well
Commercial Inj
Horizon: Basement Faults
Structure Contours
Faults
Search area
Shale Plays
Trenton
Marcellus
Albers Projection
Central Meridian: -96
1st Std Parallel: 20
2nd Std Parallel: 60
Latitude of Origin: 40
Compiled by:
Nancy Dorsey, EPA R6

FIGURE G-2: YOUNGSTOWN AREA TIMELINE OF EVENTS

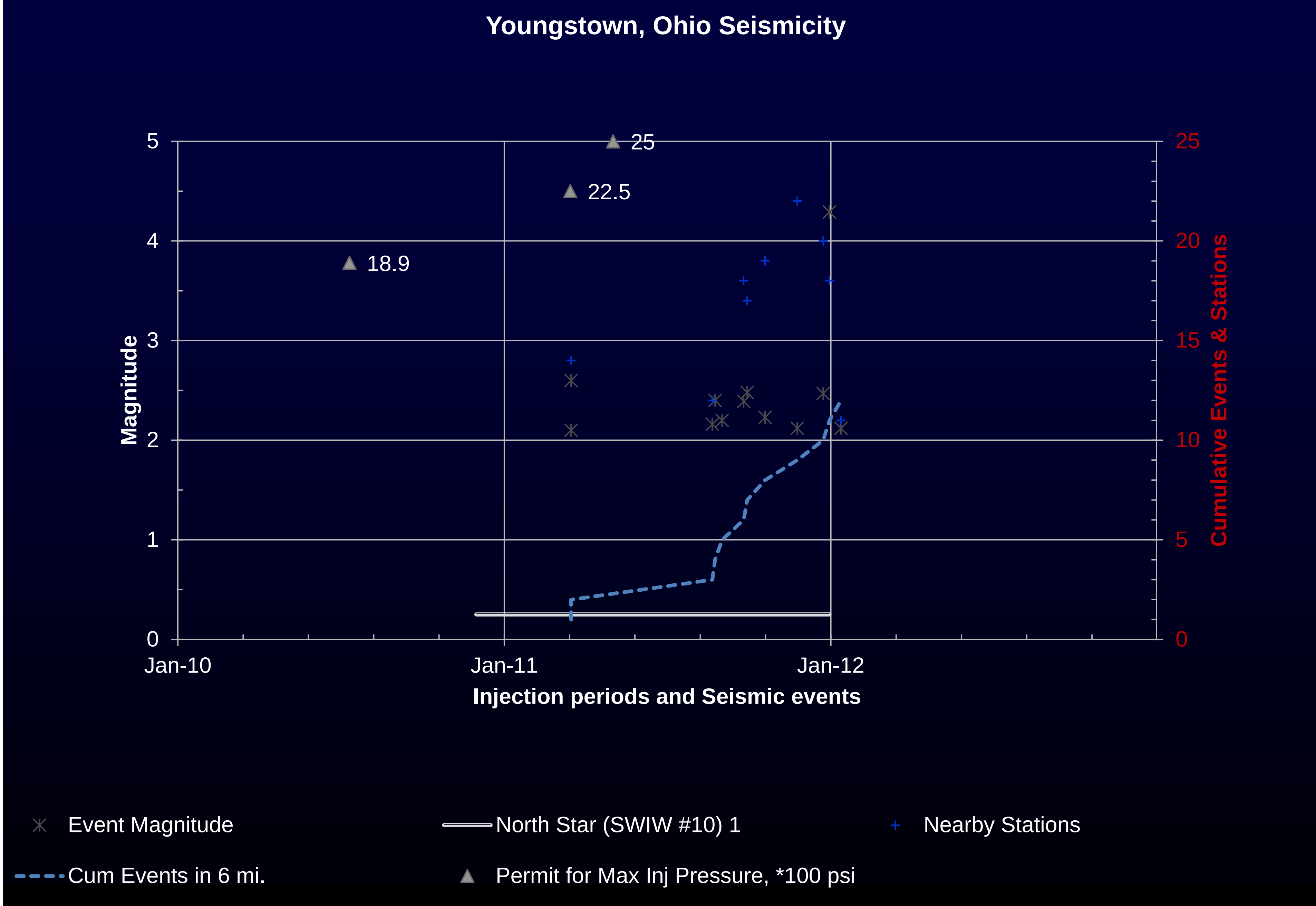


FIGURE G-3: YOUNGSTOWN AREA SEISMICITY MAP

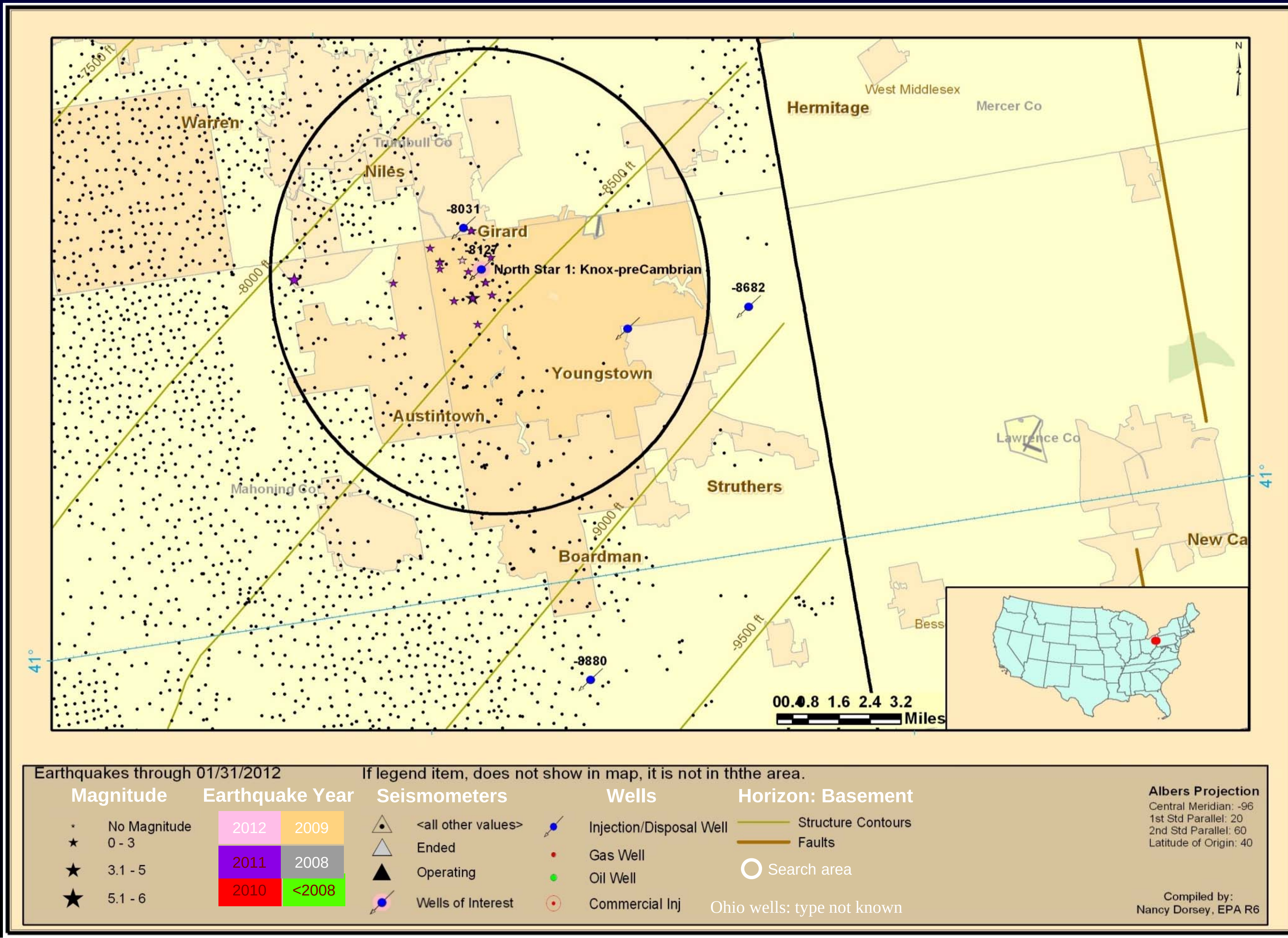


FIGURE G-7: NORTH STAR NO. 1 SWD OPERATIONAL DATA OVERVIEW PLOT

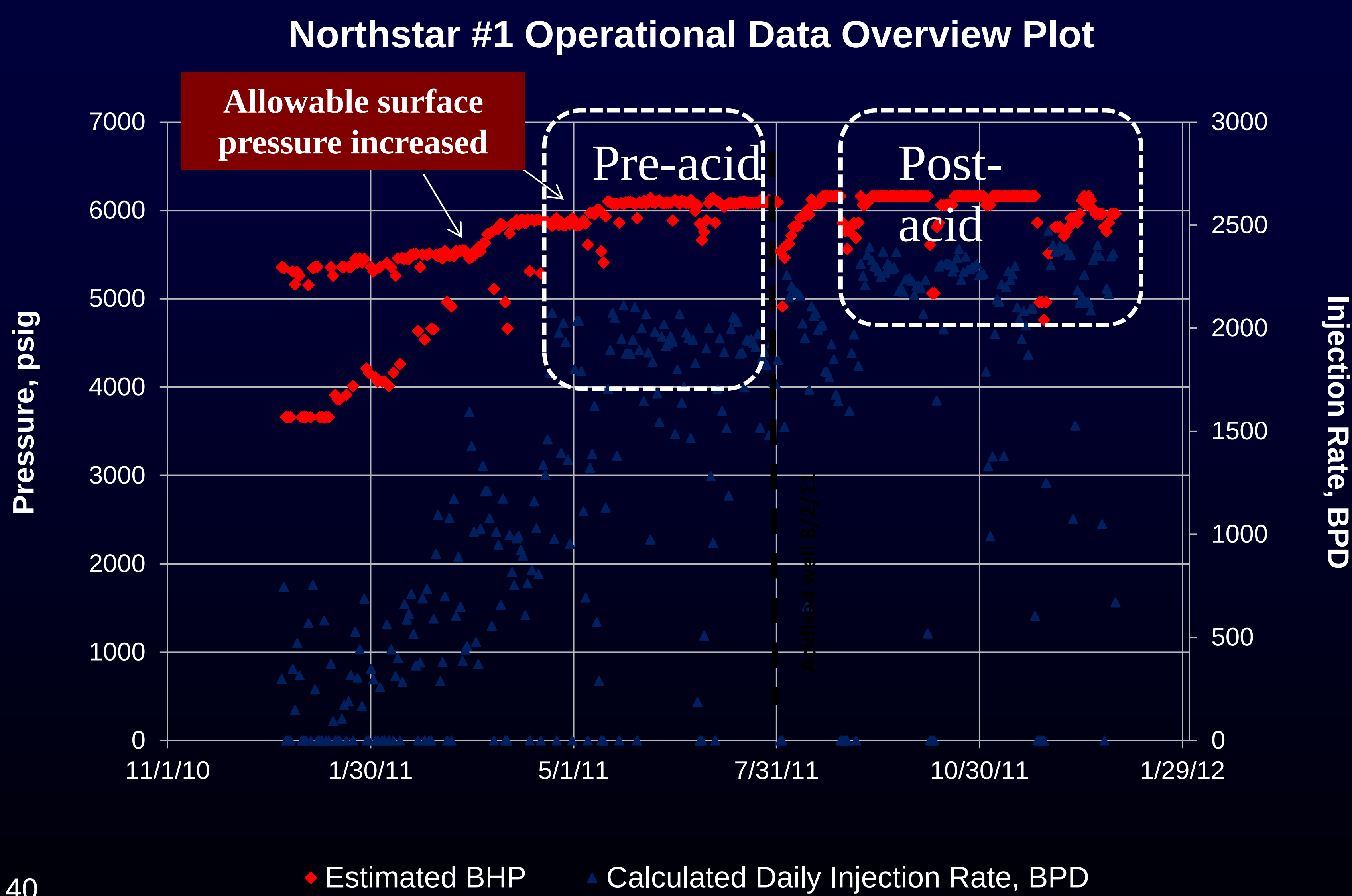


FIGURE G-9: NORTH STAR NO. 1 SWD HALL INTEGRAL AND D

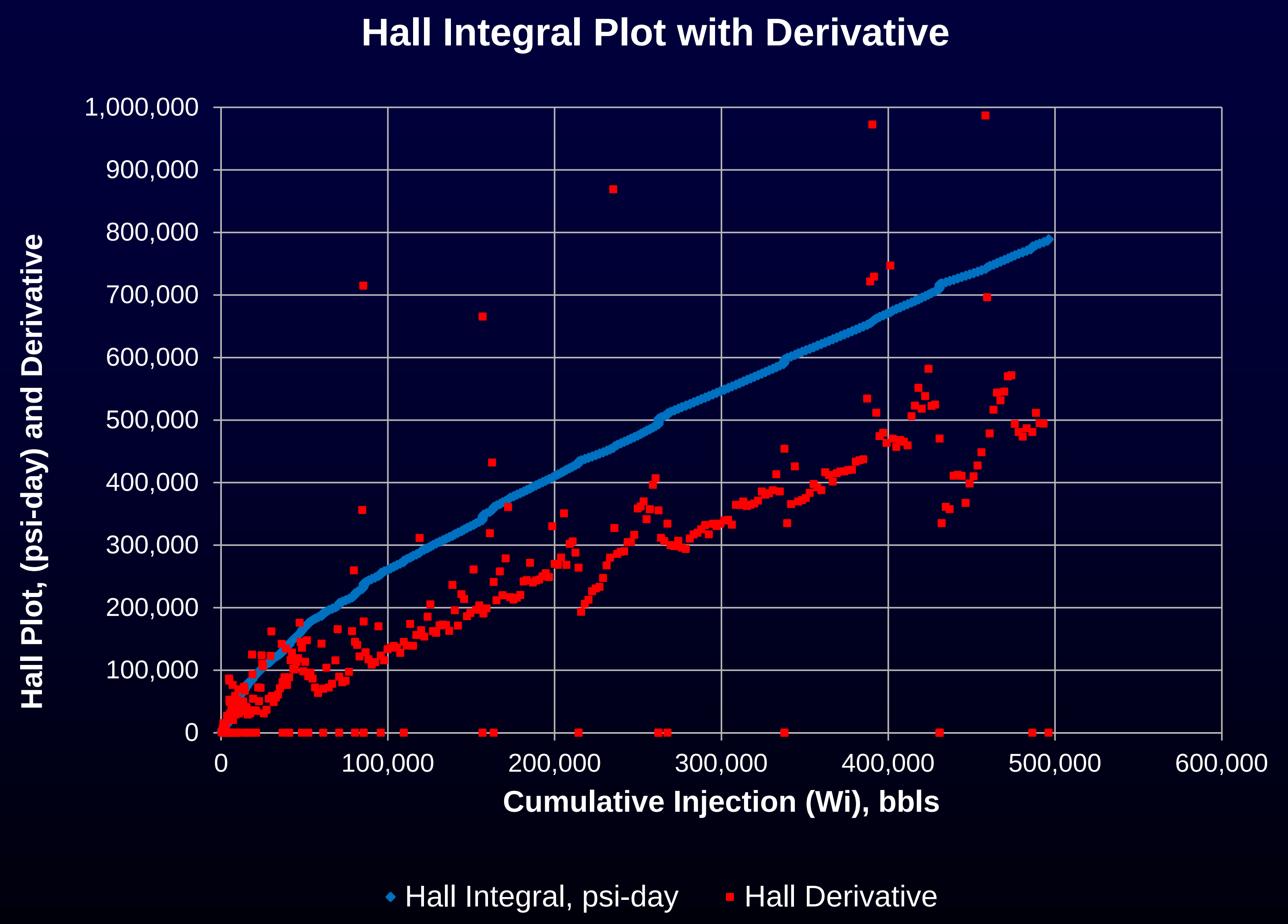


FIGURE G-10: NORTH STAR NO. 1 SWD SILIN SLOPE PLOT

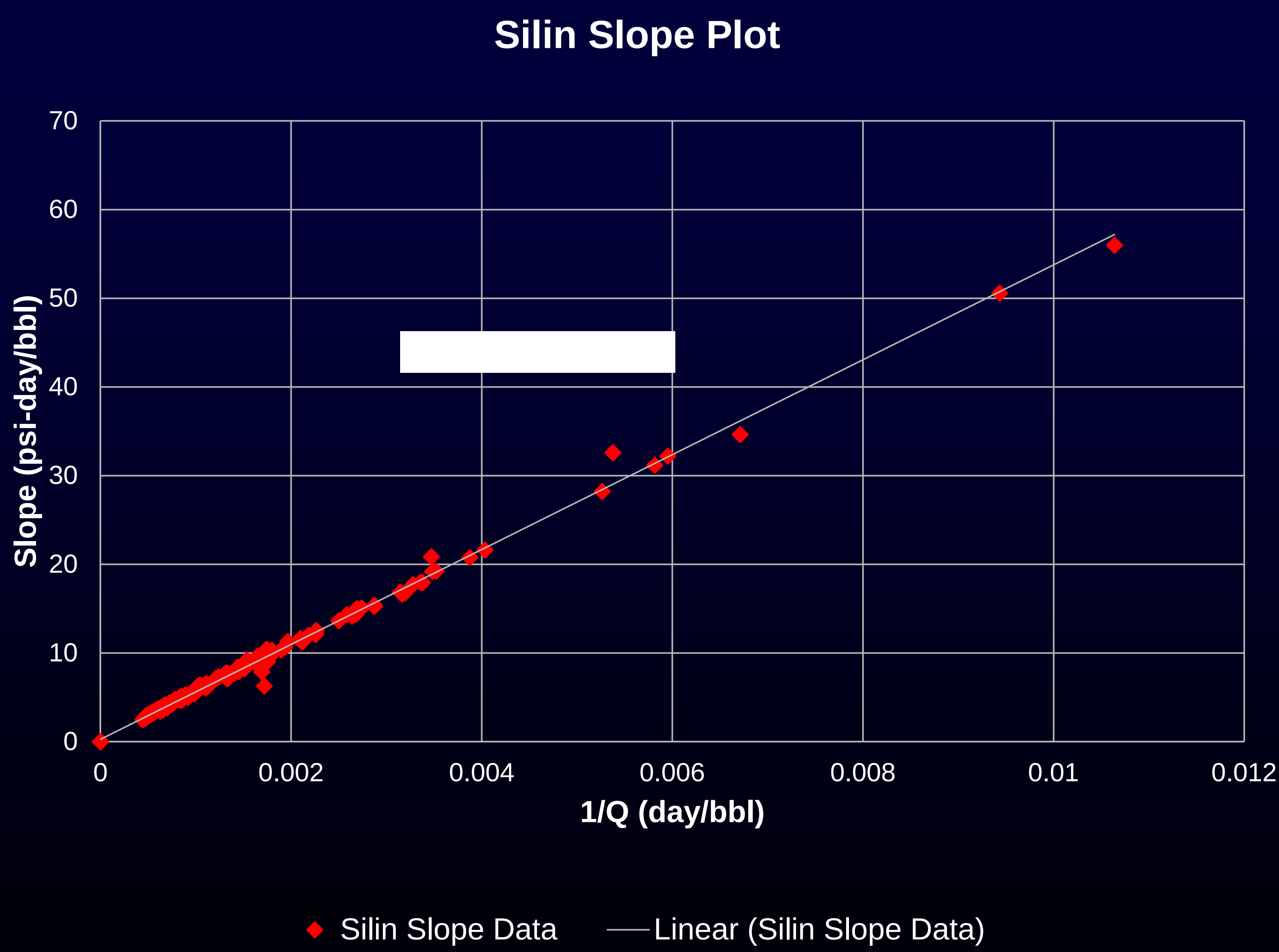


FIGURE G-11: NORTH STAR NO. 1 SWD TANDEM PLOT

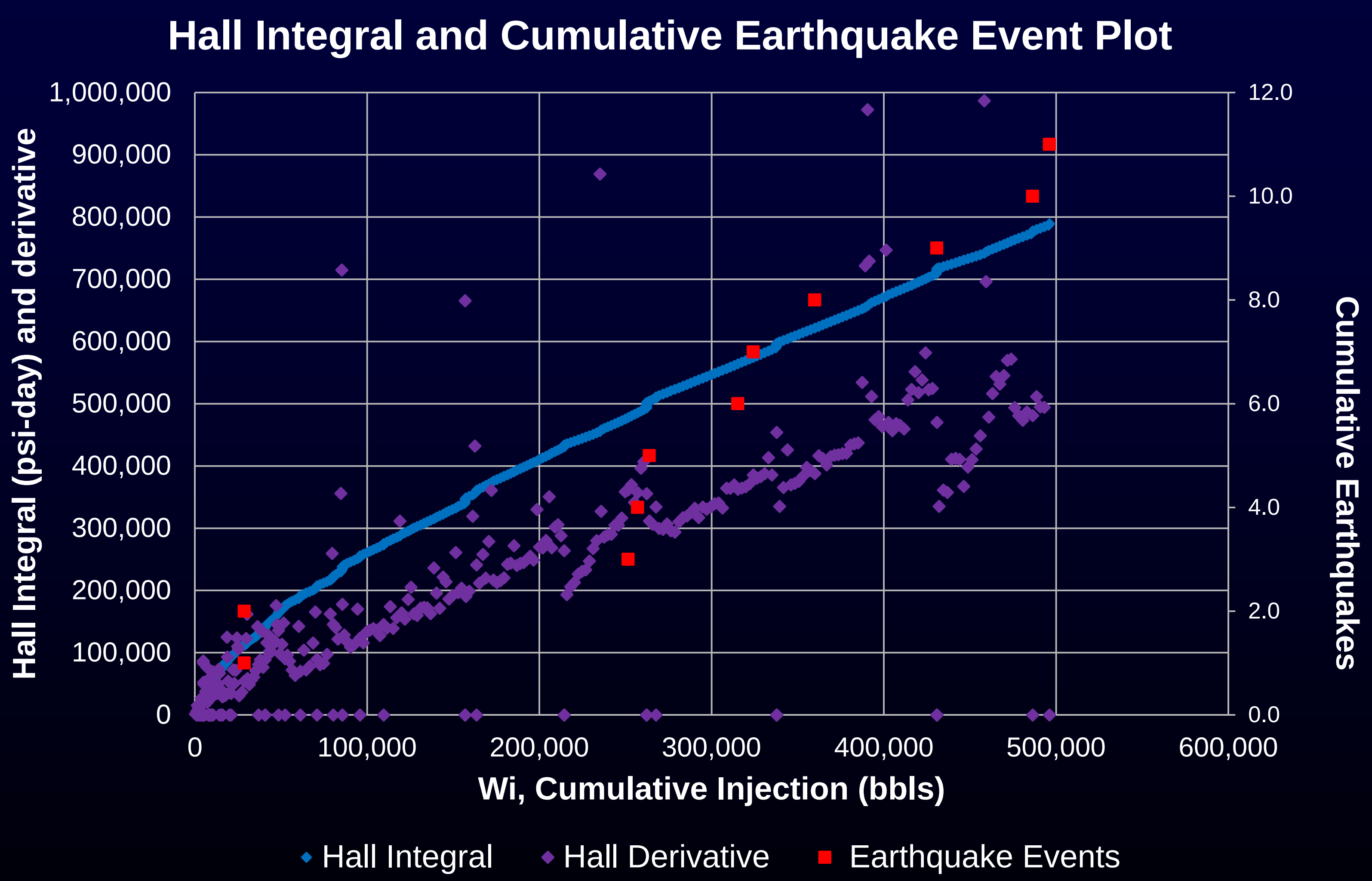
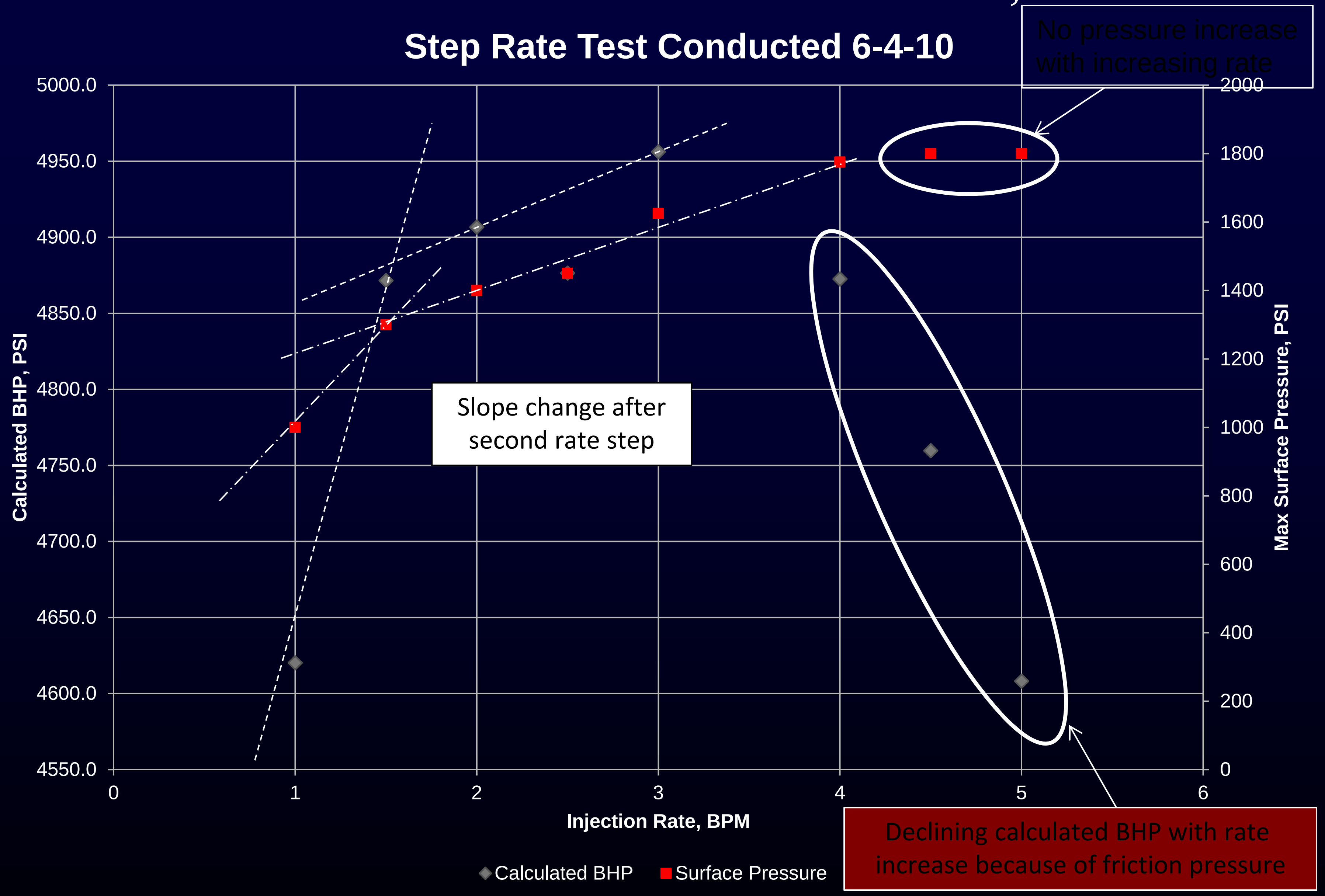


FIGURE G-12: NORTH STAR NO. 1 SWD JUNE 4, 2010 STEP RAT



Tools Used to Minimize Seismicity

Possible Tools From Case Examples and Literature

- Reduced injection rates (Braxton Co., WV)
- Engage well operators
- Engage external expertise
- Increased reporting of key injection parameters
- Moratoriums in areas believed to be high risk
- Increased number of seismometers deployed
- Reservoir analyses
- Establish action levels

United States Environmental Protection Agency
Region 6
Dallas, Texas